Need for Sustained and Integrated High-Resolution Coastal Mapping

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Abstract

The coastal zone of the United States is a dynamic environment evolving in response to both natural processes and human activities. In order to protect coastal populations and resources, a detailed understanding of the physical setting and of the processes responsible for change is required. A sustained program of mapping coastal areas provides a means to establish baseline conditions, document change, and, in conjunction with models of physical processes, predict future behavior. Recent advances in mapping technology, including airborne lidars and hyperspectral imagers, allow for the rapid collection of high-resolution elevation data and land use information on a national scale. These rich data sets are critical to evaluating risk associated with coastal hazards, such as flooding during extreme storms. For example, elevation data are the basis of storm surge models that determine where flooding will occur, and land use maps serve as the foundation of assessments identifying the resources and populations that are most vulnerable. A comprehensive, national coastal mapping plan, designed to collect, manage and distribute these data and to take advantage of recent progress in mapping technology, will provide a wealth of information for studying the processes of physical change, for determining areas vulnerable to coastal hazards, and for protecting and managing our coastal communities and resources.

1.0 Purposes of Coastal Mapping

Anyone who has visited the same beach or coastal estuary regularly has likely noticed dramatic changes in its physical characteristics. For example, the beach may be narrower or the sand dunes lower due to erosion during a recent storm. An estuary may be flooded after rivers and streams filled the wetlands with heavy rains that occurred hundreds of miles away. Our Nation's coastal areas consist of beaches, estuaries, barrier islands, rocky bluffs and headlands, coral reefs, rivers, streams, and wetlands - all responding not only to natural forcing but also to urban, sub-urban, and rural populations, development, and pressures. The coasts and their ecosystems are our most dynamic and rapidly changing resource, continually being reshaped by waves, currents, tides, floods, storms, and people. Our challenge is to understand how and why these coastal areas evolve so that we can manage natural and anthropogenic change and protect coastal populations and resources.

Currently, there is no national comprehensive inventory of existing coastal conditions and resources or of quantitative data on change and rates of change. To be successful in developing this essential information for managing and protecting our coastal areas, we must measure and monitor, which includes sustained and integrated high-resolution coastal mapping (Committee on National Needs for Coastal Mapping and Charting, 2004). This requires many types of physical and ecosystem data at spatial resolutions from centimeters to hundreds of kilometers and at accuracies that meet mapping, charting and engineering standards and uses. Today, physical and environmental information about the coast are collected, interpreted, and used by a wide range of Federal, State, and local governments, industry, and academia, with a similarly wide range of specifications and products. These data are collected to inventory existing resources, assess conditions, and forecast vulnerability to change; quantify change and rates of change; plan new developments; establish boundaries; manage sand resources; and to establish evacuation routes. While the requirements and uses of these data sets are broad and varied, the types of data collected by and the operating costs (representing tens of millions of dollars annually) of the various organizations are similarly broad and varied, highlighting the need to coordinate and share amongst those collecting data and producing products.

No better example illustrates the value of high-resolution coastal data and its many uses than the 2004 and 2005 hurricane seasons when large amounts of physical and ecosystem data were collected along the Florida, Alabama, Mississippi, and Louisiana coasts by a small number of agencies and organizations. These data were quickly used by Federal, State, and local governments, industry, and academia for storm damage assessments and reconstruction planning. One data type provided to multiple users was topographic and bathymetric lidar data collected before and after the storms by the US Army Corps of Engineers (USACE) and by the U.S. Geological Survey (USGS) with the National Aeronautical and Space Administration (NASA). These data were used by the USACE to quantify post-storm beach conditions and plan for re-construction of Federal coastal storm protection projects; by the USGS to quantify coastal change, to evaluate regional coastal vulnerabilities to storms, and to model vulnerability to future storms; by local officials and coastal consultants in Panama City Beach, FL, to assess damages to their popular tourist beach; and by academics at the University of Florida to evaluate the three-dimensional bathymetric affects on storm induced shoreline response. This is just one example of the broad use of a single data type and data collection effort that was shared by the coastal community, including government, industry and academia in response to a number of needs.

One clear lesson stands out from the 2004 and 2005 hurricane seasons that transfers easily across the nation: because the coastal zone is dynamic and ever-changing, often episodically, there must be current, synoptic data in order to accurately forecast and quantify change, particularly in response to large storm events where inundation of the coast can cause significant damage to coastal communities, habitats, and resources. This is true on all of our nation's coasts whether it is due to a hurricane making landfall in the Gulf of Mexico, a Nor'easter battering the Atlantic coast, a winter storm elevating water levels on the Great Lakes, or an El Niño event bringing large waves to the Pacific coast. Comparing data separated by years or decades without an up-to-date baseline of pre-event conditions, as is often the case, provides limited insight and knowledge into the forces or the processes that govern coastal change. If pre-and post- event-scale measurements are not timely, our ability to understand, forecast, manage, and protect is hindered.

This paper describes the tools and methods used in coastal mapping as well as the requirements and characteristics, such as frequency, resolution, and accuracy, for robust coastal mapping; demonstrates value through several applications; and defines a potential coordinated national approach to mapping.

2.0 Coastal Mapping Tools and Methods

Coastal mapping methods have advanced dramatically over the past 50 years. Mid-1900's nearshore surveys consisted of isolated transects of lead line soundings taken from the bow of amphibious vehicles (Bascom, 1954) and terrestrial surveys of the beach completed at low tide using stadia rod or stake and horizon techniques (Davis and Fox, 1972). These terrestrial surveys were eventually combined with high-tide fathometer transects using small boats, in an attempt to provide overlap with the offshore. The introduction of collimated infrared survey systems (i.e. 'total stations') using sled-based systems (Sallenger et al., 1983) or mobile platforms (Birkemeier and Mason, 1984) made it possible to cover larger areas more quickly. Today, state of the art surveys are conducted over large spatial extents with global positioning systems (GPS) and airborne lasers (Brock et al., 2002; Guenther, 1989; Irish et al., 1996; Krabill et al., 1995; Lillycrop et al., 1994; McClung, 1998; Parson et al., 1999; Sallenger et al., 2003; Wozencraft and Lillycrop, 2003; Wozencraft and Millar, 2005, and others), offshore ship-based multi-beam sonars (Mayer, 2006, for a recent review) and for the adventurous, survey-capable personal watercraft (Beach et al., 1996; MacMahan, 2001).

The surveying tools and techniques available to coastal scientists today have provided extension of capabilities in two primary directions: accuracy and speed of acquisition. While the horizontal and vertical accuracy of traditional land-based survey techniques have remained relatively constant over the past several decades, the widespread use of GPS technologies coupled with more sophisticated pitch-roll sensors for air- and water-based surveys have greatly extended our capabilities. Navigational accuracy has easily been improved over an order of magnitude in both the horizontal and vertical, to better than a meter in the horizontal, and centimeters in the vertical.

The advent of GPS technologies has not only meant better positional accuracy, but has also allowed rapid coverage of large areas. The evolution of mapping technologies has advanced from the 19th century's survey crews producing T-sheets of individual soundings acquired by lowering a lead line, through the use of increasingly sophisticated aerial photography missions, to the present use of GPS-equipped mapping platforms. The earliest coastal mapping efforts were slow and labor-intensive with national-scale coverage taking decades. The results, while remarkable given the technologies used, did not provide the uniform quantitative detail desired to address many coastal hazard issues facing our developed coastlines, such as long-term shoreline change or coastal flooding during extreme storms000000. Advances in photogrammetry, for example computer-based soft-copy photogrammetry, have greatly improved researchers’ abilities to extract quantitative information from carefully controlled missions. This technique, while extremely fast from the image acquisition perspective, requires significant time and labor for acquiring ground control points that are needed in the extensive analysis phase to georectify the images and model elevations (Hapke and Richmond, 2000; Overton and Fisher, 1996).

The earliest applications of GPS technology to coastal surveys simply involved mounting receivers on various types of vehicles and driving over the area of interest. This approach has been very useful in many studies around the country (List and Farris, 1999; Morton et al., 1993; Ruggiero et al., 1999; Ruggiero and Voigt, 2000). However, while this works reasonably well for unpopulated stretches of coast, the method can be hazardous for nesting shorebirds and recreational users of the beach. It also requires a significant amount of time to produce a full topographic map of the subaerial coastal topography. This basic approach was extended to surveys of the energetic surf zone by other researchers who developed GPS and fathometer survey systems mounted on a personal watercraft (Beach et al., 1996; MacMahan, 2001).

The most recent advances in coastal survey techniques have been the development of airborne lidar (light detection and ranging) sensors. These systems all combine three measurement systems – an inertial navigation unit, GPS and tilt sensors for measuring the position and attitude of the aircraft, and a scanning laser used to precisely measure the distance from the aircraft to the survey target. By varying the characteristics of the laser (the power and wavelength of light) the lidar systems can be used to map both topography and bathymetry (e.g. (Brock et al., 2004; Guenther et al., 1996; Krabill et al., 2002; Lillycrop et al., 1996; Sallenger et al., 2003; Wozencraft and Lillycrop, 2003;

Wozencraft and Millar, 2005), and others). While lidar survey systems have horizontal and vertical accuracies slightly greater than those of the underlying GPS-based navigation, they offer significant advantages to mapping using traditional techniques. These modern high-resolution mapping systems can easily cover hundreds of kilometers of coast in a day with point densities exceeding 1 laser shot/m^2. These densities allow the creation of high resolution topographic/bathymetric digital elevation models (DEM) that show rich details of both the natural environment and the development within the coastal community (e.g. Figure 1).

3.0 Value and Application of Coastal Mapping

Laser-based mapping systems have the spatial resolution, coverage, and accuracy to produce highly detailed and accurate elevation models of coastal topography. These maps serve to document baseline coastal conditions, assess long-term and event-induced change, and monitor short- and long-term physiographic changes to our coastal ecosystems. The use of such systems also allows for consistency of measurement technology and data analysis procedures at a national scale. In the past, studies of coastal change and vulnerability to coastal hazards were done on a local or state scale. This limited the utility of the data for assessing the vulnerability of the coast on a national scale because individual studies could not be inter-compared. More recently, lidar-based coastal mapping efforts have been used to examine historical changes to our Nation's shorelines (Morton and Miller, 2005; Morton et al., 2004). Here, the long-term rate of shoreline change was calculated by comparing historic shoreline locations to the modern-day position as mapped by lidar systems. Because a nationally consistent methodology was used to calculate the shoreline change rate, comparisons can be easily made between different areas of the coast. The lidar-based shoreline also provides an objective measure of the shoreline to which future measures can be compared. These accurate measures of position are accompanied by error bars which will allow for more detailed, rigorous, and meaningful studies of our Nation's coastal response and future vulnerability to sea level rise.

Similarly, synoptic, high-resolution topography data are the foundation for a consistent, nation-wide approach to inundation modeling and assessing vulnerability. Combined topographic-bathymetric surveys provide the detailed characterization of the coastal boundary necessary for modeling storm surge. Comparisons of modeled storm surge to up-to-date coastal topography allow for estimates of the physical vulnerability to inundation during storms (Sallenger, 2000). For example, on barrier islands, locations of the coast where the modeled storm surge elevation exceeds the elevation of the dune or island are more likely to be flooded than areas with higher coastal topography.

Lidar-based mapping systems are used not only to measure bathymetry and topography but also to map various features related to land use such as vegetation cover (Brock et al., 2001; Nayegandhi et al., in press) and tree canopies (Harding et al., 2001; Lefsky et al., 2002). These systems can therefore provide a whole-ecosystem look at coastal areas and allow for unprecedented mapping of the baseline conditions of coastal areas as well the monitoring of short- and long-term changes in beaches and marshes, land use, and vegetation canopies. Laser-based coastal mapping systems are capable of identifying infrastructure within the coastal zone that, when combined with models of physical vulnerability, can lead to an assessment of which communities are most at risk to inundation. These surveys are also invaluable for tracking coastal development and structure loss following major storm events.

The whole-system mapping approach is particularly valuable for assessing the risks associated with coastal inundation because both the physical conditions related to the hazard (i.e. low coastal topography, rapidly subsiding wetlands) and the threatened populations, habitats, and infrastructure may be considered together. Comprehensive coverage over large spatial areas provides the ability to quantify the spatial variability of both the hazard and the vulnerable areas in order to discriminate which areas are more at risk to inundation during storms.

3.1 Importance of high-resolution spatial coverage

The ability to obtain high-density measurements of topography and bathymetry make lidar-based mapping systems the preferred technique for mapping detailed elevation differences over large areas. Ground systems with more coarse sampling intervals may miss the details of coastal topography that are important when identifying areas at risk to inundation.

For example, the elevation of the dune crest, often a coastal area's first line of defense in a large storm, has been shown to be highly longshore variable (Elko et al., 2002). The elevation of the dune crest extracted from lidar surveys every 20 m over a 15-km stretch of coast in the Outer Banks of North Carolina (Figure 2) reveals a spatially complex dune structure where the mean elevation is 5.18 m and the standard deviation, σ, is 1.74 m. Sub-sampling the data with much coarser spatial resolution, such as the 1-km intervals that might be used to measure beach profiles during a ground-based survey, presents a much different picture of the dune in the area as the coarser sampling interval is unable to resolve the spatial variability of dune height (Figure 2). Depending on the locations of the discrete samples, the elevations of the dunes maybe be significantly over- or underestimated. With 1-km sub-samples, beginning immediately to the north of Hatteras Inlet, the mean elevation of the dune crests decreased by 62 cm to 4.56 m. Many of the peaks in dune height were missed making the stretch of coast look more vulnerable to large waves and surge. However, if the sub-sampling were shifted to begin just 180 m north of the inlet, the mean elevation of the dune crest now increases to 5.65 m. In this case, the variability associated with low relief in the dune crest is unresolved. It is these topographic lows that need to be mapped in order to provide an accurate assessment of the coast's vulnerability to flooding. The lidar-based survey is able to resolve the full details of the dune topography, including those lower regions which were, in fact, the locations of island breaching along this coast during Hurricane Isabel in 2003.

Not only is complete longshore coverage required for accurate assessments of inundation vulnerability, but also wide cross-shore coverage, extending inland from the shoreline. For example, barrier islands will breach where the island elevation is low and where the island width is narrow (Sallenger et al., 2004). Full-island surveys allow for the quantification of barrier island width which can be used in conjunction with dune or island elevation in determining the areas of the islands that are more vulnerable to inundation during an extreme wave event. Additionally, storm surge often is greater in inland waterways than on the open coast as water is funneled into inlets and bays.

High-resolution mapping is also important when examining beach and dune volumes. Volume computations using beach profiles are based on the assumption that alongshore and cross-shore variability is small in between measurements. Lidar surveys of the beach and nearshore have revealed a large amount of variability on even the most mundane of coastlines. Inadequately spaced profile data may not fully capture the alongshore variability of the beach, resulting in large errors in beach volume calculations. Figure 3 shows the error in beach volume resulting from cross-shore profiles equally spaced in the longshore (after Irish et al., 1996). The volume errors represent the volume error per meter of beach in the alongshore direction and are computed relative to the volume calculated with a 5-m profile spacing. Both the magnitude and variability of the volume errors increase with increased profile spacing, showing that high-resolution topographic and bathymetric surveys are essential for fully characterizing the nature of changes to a beach or dune system.

3.2 Need for repetitive mapping and adequate temporal resolution

Another critical requirement of coastal mapping for the purposes of inundation modeling or vulnerability assessment is that the topographic/bathymetric maps used are relevant to the most current conditions. After baseline mapping has been completed, up-to-date maps should be maintained by completing additional surveys on a regular basis or following major storm events. Beaches respond dramatically to the forces of wind, waves, and tide, particularly during hurricanes when the threat of inundation is the largest. Lidar surveys of the Outer Banks of North Carolina following Hurricane Isabel show striking changes to the fore dune ridge that lies between the ocean and community infrastructure (Figure 4). In the village of Hatteras North Carolina, over a 15-km stretch of coast north of the inlet, the mean elevation of the dune was reduced from 5.18 m (σ = 1.74 m) before the storm, to 3.79 m (σ = 2.07 m) after Hurricane Isabel's landfall. In the 1.5-km region surrounding a major breach across the island (longshore location = 8.5 km), the elevations of the dune crests were decreased by an average of 4 m. These hurricane-induced changes in the dune topography will have a consequence on the future storm-response of that stretch of coast, making more areas vulnerable to inundation.

Post-storm surveys of coastal topography are also used to assess the impact of the storm or inundation event on beaches, wetlands, and infrastructure. When compared to baseline surveys of the same area, the post-storm data can provide an accurate way to quantify land and structure loss. For example, lidar surveys collected over Dauphin Island, Alabama, following Hurricane Katrina's August 29, 2005, landfall were compared to a survey collected one year prior after Hurricane Ivan had made landfall on September 16, 2004, in order to document Katrina's impact on the island. The elevation difference calculated between the digital elevation models for 2004 and 2005 shows extensive shoreline erosion and overwash as the island migrated inland (over 50 m in some locations) in response to large waves and surge (Figure 5). The difference map also reveals that over 80% of the houses in this central portion of the island were lost during the storm (For additional examples from other storms, see Stockdon et al. (2003), Sallenger et al. (2004), and Sallenger et al. (in press-a)). Comparisons between pre- and post-storm surveys also allow researchers to examine the spatial variability of the storm response and the processes driving the observed patterns (Stockdon et al., in press). Through these types of studies inundation, vulnerability models can be evaluated and improved.

4.0 Defining a Comprehensive National Mapping Program

High-fidelity and high-resolution coastal and ecosystem data are of vital importance to accurate modeling of coastal inundation and assessment of the vulnerability of communities and resources. Technology has matured to meet our data needs; however, developing a coordinated coastal mapping program is essential for timely data collection, efficient data sharing, and meaningful national products. The National Research Council's Committee on National Needs for Coastal Mapping and Charting made eleven specific recommendations covering five general categories defining a national coastal mapping program including: the need for a seamless bathymetric/topographic dataset for all US coastal regions; shoreline definition protocols; easy access to timely data; data integration, interchangeability, and accuracy; improved coordination and collaboration; and increased data collection (Committee on National Needs for Coastal Mapping and Charting, 2004).

The Committee's recommendations within these categories identify important requirements for a comprehensive mapping strategy and provide a framework for defining the specifics of a national plan. Additional needs and directions can be specified based on recent developments in mapping technologies, capabilities, and analyses since the Committee's report, such as advancements in data management using GIS and data access via the Internet, as well as developing expertise in the integration of active and passive sensors (data fusion) for mapping coastal ecosystems. Expansion of the Committee's categories and recommendations to incorporate these new technologies and to further define coastal mapping requirements will produce high-quality data and products for a much wider range of coastal managers, engineers and scientists. An effective national mapping program must establish minimum mapping requirements to ensure that products can be produced to a specified standard regardless of who collects the data. A national program will also help to develop a data and information management, integration, and dissemination plan that is will guarantee the widest access and distribution.

4.1 Mapping Requirements

To support a national coastal and ecosystem mapping effort and to satisfy a majority of Federal, State, and local government, industry and academia mapping requirements, surveys of both subaerial topography and shallow subaqueous bathymetry, as well as coastal land use and ecosystem classification, are needed. For coastal counties surveys would ideally extend from the shoreline landward to the county line. While political lines serve as convenient boundaries for defining survey limits, they do not define limits for physical processes. Therefore, the spatial extent of the surveys must be designed to encompass all areas vulnerable to coastal inundation, for example, portions of inland counties with shorelines on estuaries or bays. Bathymetry surveys would be collected from the shoreline out to a depth of 30 m to encompass the most variable elements of the nearshore profile and the most critical areas for inundation modeling. In this sampling design, major data collections are repeated roughly every five years; with local/regional sampling intervals dependent on documented rates of change. In the narrow region around the shoreline, change occurs over shorter time scales and requires a higher sampling frequency, perhaps annually and certainly subsequent to major change events.

Elevations. Both subaerial and subaqueous elevations are required to create DEMs that can be used to quantify erosion and accretion, to extract building footprints, to create accurate bare earth models for coastal modeling, to ortho-rectify imagery, and to fuse elevations with spectral products for three dimensional land use classifications. Topography data collected with lidar at sub-meter postings result in high sufficiently density products, such as bare earth DEM, vegetation heights, and building footprints. Bathymetry surveys are also efficiently collected with lidar, where water clarity permits. Much of the US coastal waters are optically clear enough to use airborne lidar and a 3-4 meter posting is sufficient to produce a variety of products (Guenther, 2001). Where water conditions are not conducive to bathymetric lidar, other conventional methods, such as beach and nearshore profiles or shallow-water multi-beam acoustic systems, must be used.

Land Use and Ecosystems. To measure and monitor coastal land use and ecosystems, digital and spectral imagery are emerging as very useful tools, especially when high resolution and regional scale data are required. Digital RGB imagery is commonly used for visualization and extracting planimetric information (basic infrastructure such as buildings, roads, seawalls, jetties, piers, marinas, etc). While data resolution of 1-m pixels is common, some more detailed change analyses require 30-cm pixels. Figure 6 shows a Mississippi River coastal protection levee following Hurricane Katrina. In the upper two panels the topographic lidar DEM (a) and RGB imagery (b) are useful for looking at conditions at the time of the survey. Expanding imagery collection to include additional spectral bands greatly increases the measuring and monitoring capabilities and the utility of resulting products. Use of this technology in the coastal zone is new, but shows great promise (Wozencraft and Lillycrop, in press). Figure 6 (c) shows an application of these data by illustrating ecosystem health determined using basic spectral information. The areas near the levee were flooded by Katrina, stressing the nearby vegetation (indicated by a dull red). Areas in bright red near the bottom of the image show un-disturbed marsh vegetation. More advanced image analysis provides classification of image pixels. In Figure 6 (d), vegetation is distinguished from different soil cover types and water types. Other uses include classifying wetland species, measuring submerged aquatic vegetation, evaluating coral reef health, and identifying underwater bottom type (sand, seagrass, mud, coral, etc.,(Tuell et al., 2005)).

4.2 Data Integration and Accessibility

Data integration and accessibility are as important as data collection. Specific data types, such as habitat mapping based on geo-positioned spectral imagery, may be very valuable as a stand alone product. However, these products may be improved and expanded by combining them with other data and information sets. Without integration methods defined at various stages in the data life cycle, much information may be lost or inadequately utilized, creating the need and expense for additional or duplicate data collection. Three methods to integrate data and information and to provide for data access are data fusion, Geographic Information Systems (GIS), and web-based access.

Data Fusion. Fusion, an emerging capability in the coastal mapping community, is defined as the combining of sensor-level output from two or more instruments or models to produce data and products that neither could have produced alone. Much of this effort is being pushed forward by the Joint Airborne Lidar Bathymetry Technical Center of Expertise, a partnership between the US Naval Meteorology and Oceanography

Command, the USACE, and the NOAA National Ocean Service. The Joint Center operates the Naval Oceanographic Office's CHARTS coastal mapping and charting system, which is an integrated topographic lidar, bathymetric lidar, digital RGB camera, and hyperspectral imager. New fusion products combining output from these active and passive coastal mapping sensors are yielding very promising data and products ((Wozencraft and Lillycrop, in press), e.g. Figure 6). Another leading body of fusion research and development is through a partnership between USGS and NASA, using the EAARL topographic and bathymetric lidar and a multispectral digital camera (Brock et al., 2004).

Geographic Information Systems (GIS). With increasing use of airborne lidar, the largest challenge facing coastal geologists and engineers has been developing data processing and visualization tools for very large data sets. As with other disciplines relying on remotely-sensed data, the use of GIS software has been one common approach. With GIS tools, various coastal mapping data can be combined as geo-referenced thematic layers to create maps for use by scientists, engineers, and resource managers. In addition to maps, data managed through a GIS provide a method for long-term storage of data and the development or augmentation of an organization's institutional body of knowledge. GIS is a widespread tool in many coastal mapping organizations because of these two powerful features. Once data are stored in standardized geodatabases, common tools can be developed and shared nationally to analyze data and extract information. This is being realized through Federal programs such as the USACE eCoastal tools and enterprise GIS architecture, designed to eventually link all USACE coastal district offices to access, analyze, and share data (http://ecoastal.usace.army.mil) and the NOAA Coastal Services Center's GIS conference GeoTools (http://www.csc.noaa.gov/geotools). Many other Federal, State, and local governments, industry and academia have similar and complementary tools, making GIS technology a preferred method for organizing and visualizing these large datasets.

Web Based Data Integration. The greatest potential for well-organized and economical data access is through web-based connections and interoperability between systems. GIS provides the framework to manage, analyze and share data, but it is through web-based connections that the greatest potential exists for efficient, wide-spread data sharing and use. Programs such as Federal Geospatial Data Committee's (FGDC) GeoSpatial One Stop are establishing data format standards, communication protocols, and a forum for connecting and cascading data from one organization to another. The USGS has created a clearinghouse of lidar data (Center for Lidar Information, Coordination, and Knowledge, http://lidar.cr.usgs.gov/) to facilitate data access and user coordination. An example of multi-agency data access is through the Gulf of Mexico Alliance's Priority Habitat Information System (PHINS, http://gis.sam.usace.army.mil/a023/default.aspx), which includes a digital library for locating data and a viewer that displays selected data from multi-agencies to produce maps.

4.3 Implementation Plan

There are over 8,000 miles of open coastline in the continental US, excluding bays, estuaries, nearshore islands, and Alaska. Mapping these areas to create an initial, comprehensive inventory, much less mapping them on a continuing basis to quantify change and maintain currency of information, is a substantial challenge. An implementation plan is needed to fulfill national mapping requirements such as those identified in section 4.1, establish the frequency for repetitive mapping, provide data collection and product standards, and ensure broad dissemination of data and information. Based on initial assessments of coastal mapping needs and capabilities by several Federal agencies, including USACE, USGS, NASA, and NOAA, a national implementation plan should be developed to map the United States' coastal areas with sufficient frequency to ensure that data are up-to-date and relevant. This plan would include mapping of elevations and ecosystem resources to quantify coastal, land use, and habitat status and change, to support coastal change forecasts and vulnerability assessments, and to provide the data foundation for the many other products described herein. The narrow region along the shoreline of sandy coasts where change occurs rapidly should be re-mapped frequently, using lidar and spectral imagery for elevations and ecosystem measurements, as required to document change and maintain a current characterization of resources and vulnerability. Stable shores, such as some rocky areas on the Maine coast, may only need infrequent re-mapping. A nominal five-year sampling interval should be sufficient for most coastal-county-scale collection efforts. However, the primary objective in defining repeat intervals is to ensure that the resulting data and information products reflect current conditions and meet the needs of the coastal zone and resource management communities.

Three important elements are required to produce and implement a national plan: (1) a coordinating mechanism, (2) an objective method for prioritizing areas to be mapped, and (3) resources. First, efforts are required to bring together the many agencies and organizations that will be and should be involved. Coordination efforts are currently the focus of the NSTC Interagency Working Group on Ocean and Coastal Mapping, established through the President's Ocean Action Plan. This group is charged with identifying and coordinating Federal mapping programs to ensure effective and efficient development, provision, and application of ocean and coastal mapping information. Secondly, the plan must establish a procedure for prioritizing mapping requirements (survey specifications, spatial coverages, sampling frequency, etc.). Prioritization must be responsive to federal, regional and State needs and include objective criteria for identifying critical information gaps. Existing models of coastal inundation vulnerability (Sallenger, 2000) and estimates of historic shoreline change are examples of the types of inputs that might be used prioritize the location and frequency of mapping programs. Finally, the resources for carrying out a systematic and sustained mapping program must be developed. There is not sufficient capacity in the existing airborne lidar and spectral mapping community, and additional sensors would be needed, to meet the order of magnitude requirements outlined above. As the compelling benefits of a comprehensive and sustained coastal mapping program becomes ever more apparent, we envision demand will outstrip current resource availability. Addressing the resource gap will be required to continue the collaborative engagement of the public and private sectors that has long been the hallmark of mapping programs in the United States.

5.0 Summary

At the beginning of the twenty first century, we have seen a rapid evolution in the technologies to systematically measure and monitor our coastal lands and waters. The need for these data is clear - nature is continuing to change our coasts in dramatic ways and these changes are exacerbated by development and human pressures and stresses. Technologies, including airborne lidars and spectral imagers, have reached a maturity that allows efficient and cost effective high-resolution, regional-scale mapping of physical conditions and ecosystem resources. Organizationally, Federal, State, industry, and academia are cooperating in formal and informal working groups and sharing data and information. However in order to produce comprehensive coastal and ecosystem mapping to quantify conditions and document change on a national scale, a comprehensive and sustained coastal mapping plan should be defined. It is through this timely confluence of need, technology and organization that we have an opportunity to move forward and establish a sustained and integrated high-resolution coastal mapping program for the Nation.

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Figure Captions

Figure 1. Topographic/bathymetric DEM near Fort Lauderdale, Florida, with sub-meter topographic lidar postings and 4-m bathymetric lidar postings. Survey covers a 1.5 km wide swath using topographic lidar (from the shoreline to 500 m inland) and bathymetric lidar (from the shoreline to 1000 m offshore). The system used to collect data was the Naval Oceanographic Office CHARTS.

Figure 2. Elevation of the dune crests in Hatteras, North Carolina, measured every 20 m over a 15-km area north of Hatteras Inlet, before Hurricane Isabel made landfall. The data were sub-sampled at 1-km intervals showing that the details of the dune elevation are missed. In scheme 1 (dashed line) much of the spatial variability associated with the highest dunes was missed, and the mean elevation decreased to 4.56 m. In scheme 2, where sub-sampling was shifted 180 m alongshore, the elevation of the dunes was often overestimated and the mean value increased to 5.65 m.

Figure 3. Variability in beach volume error per alongshore meter of beach calculated from lidar data at four different beach sites monitored by the USACE. As spacing between the profiles increases, the error in the volume calculation also increases. (after Irish et al., 1996)

Figure 4. Elevations of the dune crests in Hatteras, North Carolina, measured every 20 m over a 15-km area north of Hatteras Inlet, before (gray, September 16, 2003) and after Hurricane Isabel (black, September 21, 2003). As a result of the storm, the mean elevation of the dune crest decreased from 5.18 m to 3.79 m, increasing the area's vulnerability to inundation during future storms. The gaps in the post-storm data indicate the locations where the island was breached and the dune was destroyed during the storm.

Figure 5. Elevations of Dauphin Island before (a, September 2004) and after (b) Hurricane Katrina's August 29, 2006, landfall. The difference image (c) shows

significant erosion of the seaward side of the island and deposition sediment in overwash fans on the sound side, as seen in the photograph taken two days following landfall (d). The difference image can also be used to assess structure loss (red squares in panel c) following the storm. The system used to collect the data was NASA EAARL. (modified from Sallenger et al., in press-b)

Figure 6. Mississippi River coastal protection levee, October 2005. (a) One-meter topographic lidar DEM, where elevation increases from blue to green to red (b) One-meter pixel red-green-blue digital image (c) Vegetation health (bright red – healthy, muted red - stressed) (d) GIS formatted thematic layer where colors indicate land cover type: blue = roadways, slabs, or sandy debris; yellow = canal water; cyan = marsh water; red = vegetation; green = muddy debris. The system used to collect the data was the Naval Oceanographic Office CHARTS.


N
Elevations relative to NAVD88
High : 25m
Low : -15m
Kilometers
0
0.25
0.5
0.75
1

Figure 1

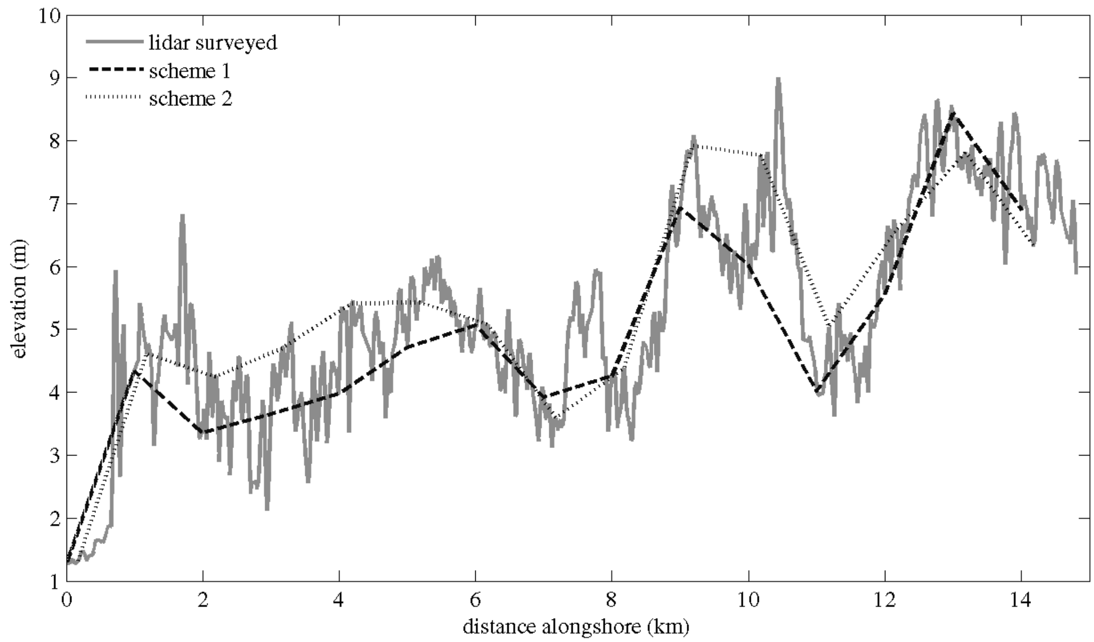
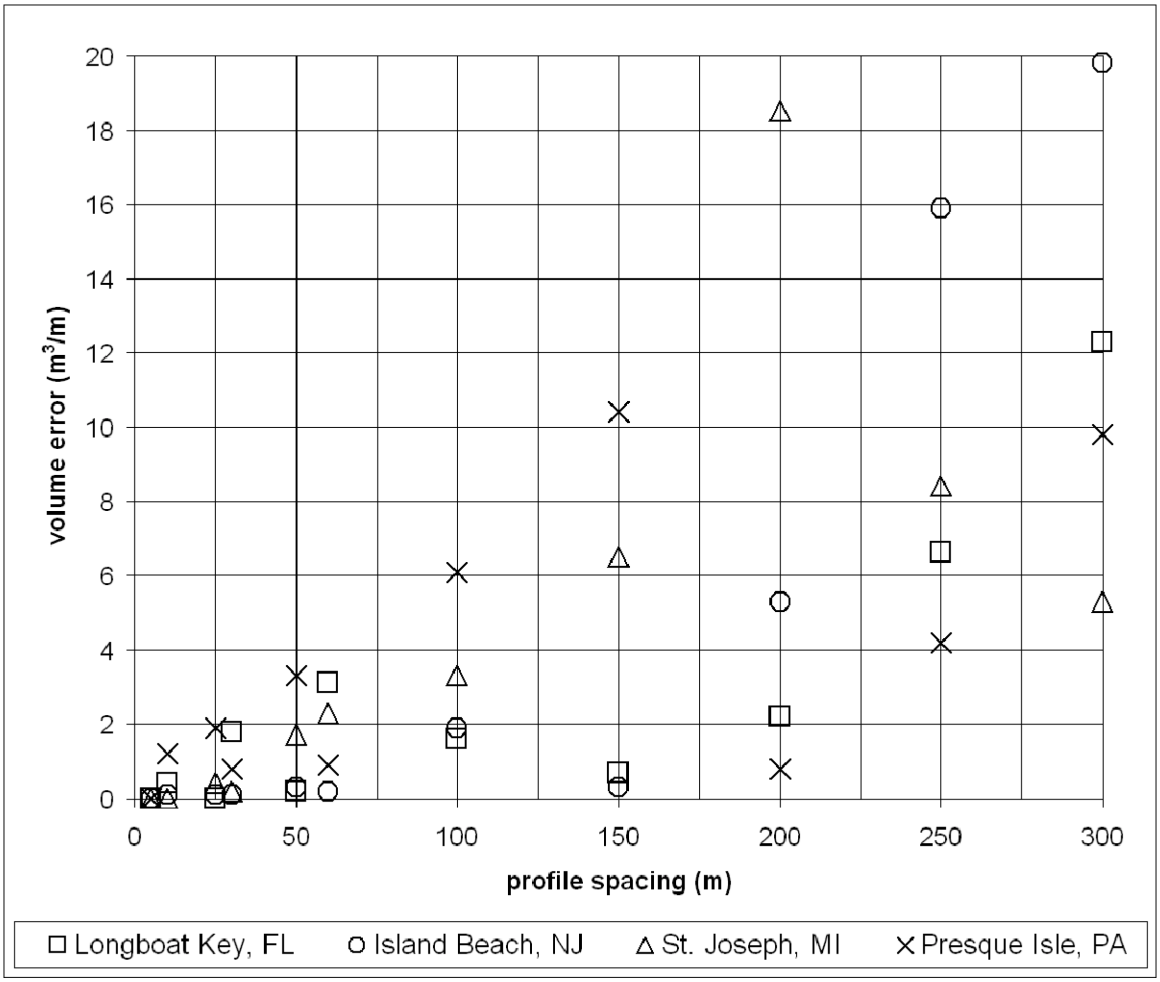
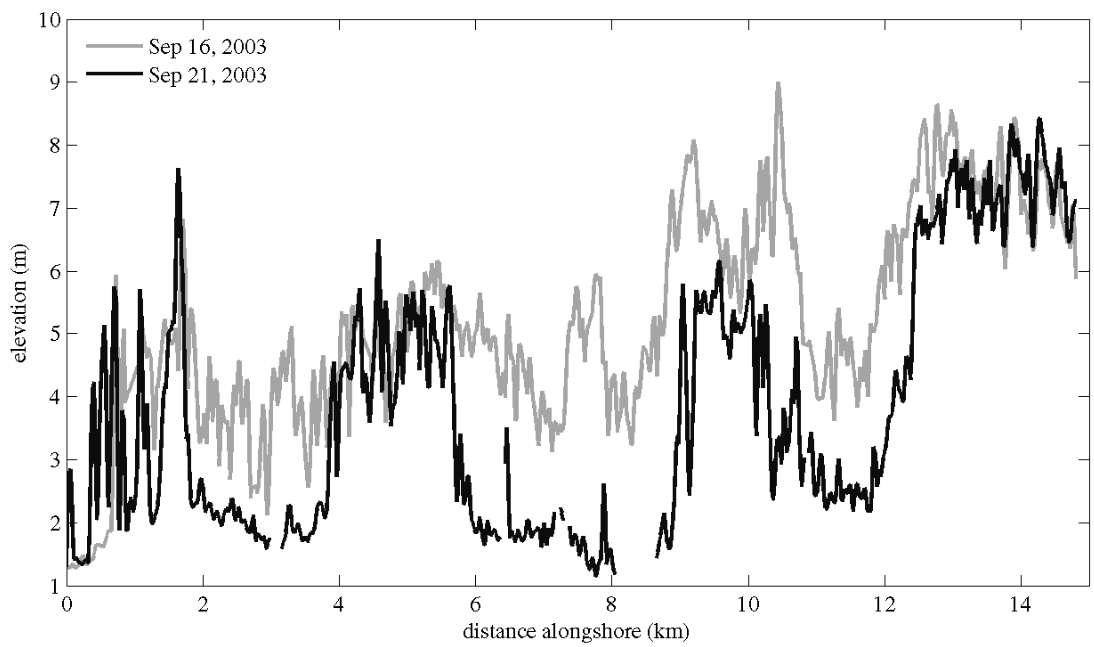

lidar surveyed
scheme 1
scheme 2
elevation (m)
distance alongshore (km)
10
9
8
7
6
5
4
3
2
1
0
2
4
6
8
10
12
14

Figure 2



20
18
16
14
12
10
8
6
4
2
0
volume error (m3/m)
0
50
100
150
200
250
300
profile spacing (m)
Longboat Key, FL
Island Beach, NJ
St. Joseph, MI
Presque Isle, PA

Figure 3



Sep 16, 2003
Sep 21, 2003
elevation (m)
distance alongshore (km)
10
9
8
7
6
5
4
3
2
1
0
2
4
6
8
10
12
14

Figure 4

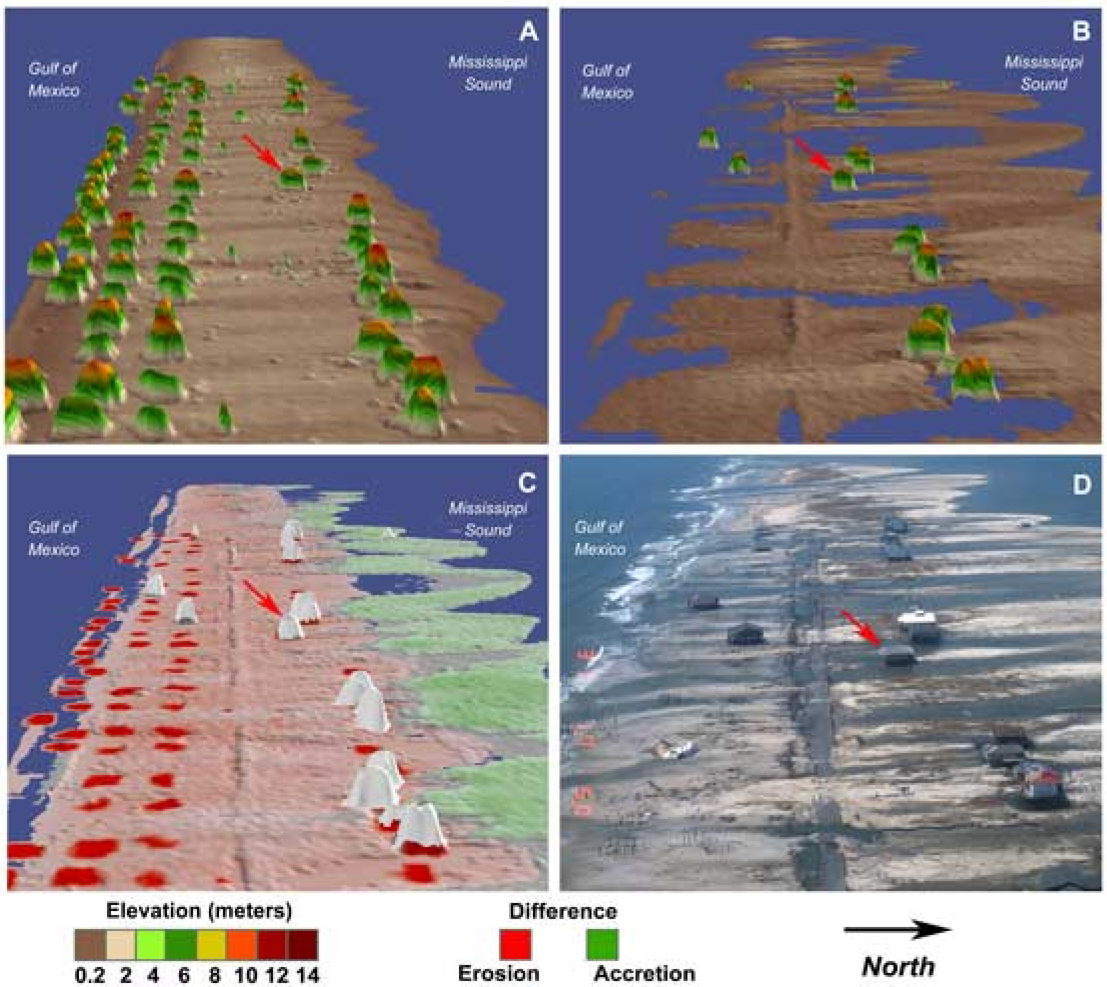

A
Gulf of Mexico
Mississippi Sound
B
Gulf of Mexico
Mississippi Sound
C
Gulf of Mexico
Mississippi Sound
D
Gulf of Mexico
Elevation (meters)
0.2 2 4 6 8 10 12 14
Difference
Erosion
Accretion
North

Figure 5

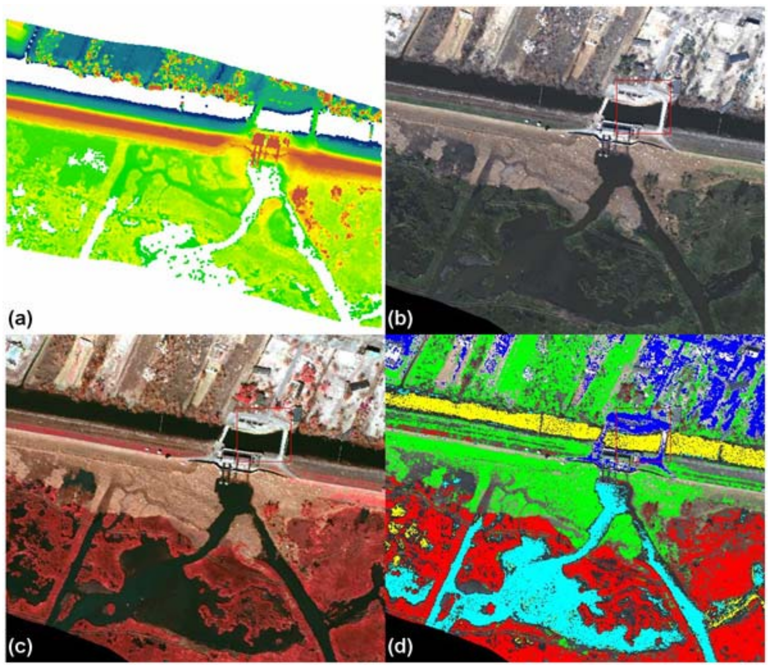


Figure 6